A Comprehensive Optimization Model Based on Time and Cost Constraints for Resource Selection in Data Grid

Qu Ming-Cheng
School of Computer Science and Technology, Harbin Institute of Technology, Harbin, 150001, China;
Email: qumingcheng@126.com

WU Xiang-hu, YANG Xiao-zong
School of Computer Science and Technology, Harbin Institute of Technology, Harbin, China;
Email: Wuxianghu@hit.edu.cn;yxzong@hit.edu.cn;zuodc@hit.edu.cn

Abstract—**Parallel data transmission based on multi-copy can enhance transmission speed and ensure the QoS of data grid greatly. The status of network and replica node, the distance of replica node, the time and bandwidth of service requester will directly affect service cost. How to take the above factors into account, so as to provide basis for node selection and bandwidth allocation, guarantee the time constraint of service requestor and optimize service cost is a key problem need to be solved urgently. Based on '0-1' integer programming and linear programming methods, respectively, a minimum transfer time model, minimum cost model and comprehensive optimization model are proposed to solve the above problem. Simulative experiments show that the models are correct and effective.**

Index Terms—**resource selection optimization model, transmission time constraint, parallel data transmission, data grid, QoS**

I. INTRODUCTION

Reliable and fast data transfer is a basis to guarantee the QoS of data grid [1]. It can greatly improve transfer speed, decrease network traffic and guarantee QoS of grid by deploying data replicas in hot area [2, 3]. GridFTP provides a striped data transmission mode [4-5]. All kinds of parallel transmission algorithms based on GridFTP, by downloading different data block from different replicas concurrently, improve download speed further[6,7].

Chao-Tung Yang [6-8] proposed a parallel transmission algorithm and a replica node selection model, the model considers the parameters of network bandwidth, status of CPU and I/O, and can output the service node set to achieve the objective of minimum transmission time. In order to improve the performance of parallel computing, Dafei Yin [9] proposed a simple replica node selection model, considering data redundancy and parallelism, attempt to establish a compromise between the two parameters. Similarly, Gaurav [10] put forward a linear optimization model to minimize transmission time. Husni [11] also adopted some strategies to select the replica node, and simply guarantee the minimum transmission time, so that the job can be finished quickly.

Related researches about parallel transmission based on multiple copies more focus on maximizing the data transmission speed. However, these studies have certain shortcomings: (1) not all of the data transmission service requests are required to be completed in the minimum possible time, more are required to be completed during a certain period of time; (2) meanwhile with little attention to: how to select node to optimize service cost, and with little consideration to network bandwidth constraint of requestor and the sensitivity of service requester to transmission time. If the grid system tries to ensure that each service request get minimum transfer time, it will certainly led to the increase of the overall service costs, so in peak time the acceptance rate and QoS will decrease dramatically.

An important problem now should be solved is: how to select replica node reasonably under the constraints of transmission time, to obtain a comprehensive objective of decision-making, including transmission speed, transmission distance, network status, requester bandwidth etc. So we can get a set of optimal service nodes, further we can get a multiple optimal objectives of decreasing network traffic, improving acceptance rate and QoS in peak, and guaranteeing a reasonable service costs. So a comprehensive decision-making model based on the status of grid system and the constraints of service requests is urgently needed.

II. BASIC CONCEPTS

A. Fundamental Analysis

For a parallel transmission service, first we should consider how to choose replica nodes. During this process we should comprehensively consider the distance between requester and replica node, the status of network links, the effective bandwidth that the replica node can provide and its status, and ensure the aggregated bandwidth that participating nodes can provide and the

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effective bandwidth of requester are rational. Then we must configure reasonable transmission speed for each parallel transmission channel, thus, in the premise of satisfying the transmission time, we can optimize the overall service cost.

Network cost: During the process of parallel transmission, the applicant downloads data from different replicas by a certain speed, as shown in Figure 1. Data move in the channels has brought a load to the network, and result in a cost. If a link that a channel must pass is busy, then the cost will be great when the data crosses it, accordingly, the more data crosses this channel, the more cost will be.

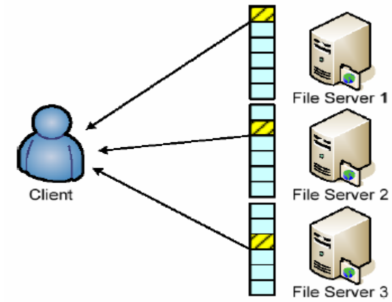

Figure 1. Striped transmission mode of GridFTP

Node cost: When replica nodes provide services to applicants, the service cost includes: connection cost and bandwidth cost. They both increase with time, and meanwhile the connection cost will increase with the amount of provided bandwidth also.

B. Symbol Definition

By the above analysis, the basic symbols used in model deduction are defined as follows:

TABLE I . Key symbols used

M:	Size of data file;
k:	Sum of replicas;
N_i:	A replica node, $(1 \le i \le k)$
B_i:	Maximum effective bandwidth from node N_i to service applicant
V_i:	Actual download speed from node N_i to service applicant;
V_a:	Actual bandwidth that the requester can achieve.
C_i:	Cost that transfer per unit data at per unit time from node N_i to requester;
W_i:	Cost that node N_i provides per unit bandwidth at per unit time;
A_i:	Cost for connection to node N_i at per unit time;
Q:	Effective maximum bandwidth of Applicant;
t_m:	Maximum transmission time constraint of applicant;
t_u:	Minimum transmission time that the applicant can achieve under current status of grid;
t:	Actual data transmission time;
z:	A positive which is greater than 0 and less than 1, is used to configure the lower limit of transmission speed from node N_i;
ω:	Weight factor for comprehensive optimization model, can be used to balance transfer time and service cost;
U:	Cost function for a data transmission service;
x_i:	0-1 decision variable, indicates that node N_i participates service or not;
y_i:	Decision variable, indicates that the actual transmission speed from N_i;
Cost:	Service cost;

C. Optimization objectives and basic constraints

Various algorithms based on GridFTP and multiple replicas, by assigning different data block from different replicas concurrently, make the requester download more data from the faster node. Its essence is to ensure each download process is uninterrupted, so as to obtain a maximum speed and minimum time.

Basic constraints:

(1) In a data service there must be some replica nodes involved in service and the others not. Let decision variables x_i represents that whether N_i is involved in service or not, here value '1' represents participance and value 0 represents not. See formula (1).

$$x_i = 1, 0 \quad (1 \le i \le k) \tag{1}$$

(2) The effective transmission speed from N_i during a data service is defined as decision variables y_i. Here y_i must be less than or equal to the maximum effective link bandwidth from N_i, and it cannot be infinitely small, see equation (2) below.

$$zB_i \le y_i \le B_i \quad (1 \le i \le k, 0 < z < 1) \tag{2}$$

(3) The network bandwidth of requester has a certain threshold limit (Q), the actual transmission speed cannot exceed the threshold, see Equation (3). The threshold can be set according to the normal maximum bandwidth that the requester can achieve.

$$\sum_{i=0}^{k} y_i \le Q \tag{3}$$

(4) The minimum time for a parallel transmission service can be expressed as:

$$t_u = \begin{cases} M/Q & \sum B_i \ge Q \ (a) \\ M/\sum B_i & \sum B_i < Q \ (b) \end{cases} \tag{4}$$

(5) The maximum transmission time constraint of applicant (t_m), the minimum transmission time that the applicant can achieve under current status of grid (t_u), and the actual data transmission time (t) must meet the constraint of formula (5)

$$t_u \le t \le t_m \tag{5}$$

At the premise of satisfying the transmission time constraint, we should decrease transmission time and the whole service cost as much as possible. So that, the grid system can provide better service for more requests in peak time, and the acceptance rate and overall QoS can also be increased to a certain extent.

From the optimization objectives and the type of decision variables (x_i, y_i) we can know that the optimization model are '0-1' integer programming and linear programming problems.

III. RESOURCE SELECTION MODEL

In this section, we first present two basic optimization models, as they both have some limitations, and then based on them an extended comprehensive optimization model is proposed.

A. The minimum transmission time model (A)

Currently, most researches about parallel transmission based on *GridFTP* tend to minimize transmission time, and pay little attention to network bandwidth of requester. In this section we give a node selection model. The model takes minimized transmission time as objective, and the bandwidth of requester as constraint, see formula (6).

The minimum transfer time can be calculated by two situations, such as formula (4). When 4-(a) is met, minimum transfer time t_u=M/Q; and when 4-(a) is met, t_u=M/∑B_i.

$$\min Z = \sum_{i=1}^{k} x_i B_i \qquad s.t. \begin{cases} x_i = 0,1 \ (i = 1,2,...,k) \\ \sum_{i=1}^{k} x_i B_i \geq Q \end{cases} \tag{6}$$

The model can output the minimum transmission time, the set of participating nodes. But the model only seeks to minimize transmission time and ignore the impact of network load. The participating nodes may be far apart, the transmission path may be very busy, which will bring greater pressure on the network. At the same time the status of replica nodes are not considered too. Both factors will lead to excessively high cost.

As the optimized aggregated bandwidth is greater than threshold of requester, how to configure the actual transmission speed for every channel, in order to optimize the service cost, is not considered in this model too.

B. The Minimum Cost Model (B)

Reducing the cost of each service request can enhance the acceptance rate and Qos of grid system in peak time. If decision variable y_i is equal to 0, it indicates that node N_i does not participate in current service. If the download speed from node N_i is too small, it will decrease the utilization of replica node. Because the connection itself will cause some CPU overhead, it is necessary to set the lower limit for download speed, see equation (7)-d.

The minimum cost model is represented as formula (7). Optimization goal minZ consists of two parts: the transmission time $M\big/\sum_{i=1}^{k} y_i$ is the left part and the transmission cost at per unit time is the right part. By the meaning of y_i, C_i, W_i, A_i, the cost formula at per unit time can be represented as $\sum_{i=0}^{k} y_i(C_i + W_i) + A_i$. So the optimization equation (7)-a indicates the minimum service cost for a request.

$$\min Z = \left(M\Big/\sum_{i=1}^{k} y_i\right)\left(\sum_{i=0}^{k} y_i(C_i + W_i) + A_i\right) \qquad (a)$$

$$s.t. \begin{cases} M\big/\sum_{i=1}^{k} y_i \leq t_m & (b) \\ \sum_{i=0}^{k} y_i \leq Q & (c) \\ zB_i \leq y_i \leq B_i, \ i = 1,2,...,k & (d) \\ A_i = \begin{cases} A_i & y_i > 0 \\ 0 & y_i = 0 \end{cases} \ (i = 1,2,...,k) & (e) \end{cases} \tag{7}$$

Constraint equation (7)-b represents that the actual transmission time must meet the constraint of maximum transmission time (t_m) given by requester; constraint equation (7)-c represents that the aggregated bandwidth must be less than or equal to the current maximum bandwidth of the requester; constraint equation (7)-e represents that if the connection with N_i is established, the connection cost takes A_i, else takes 0.

This model outputs the minimum service cost and the actual transmission bandwidth from every replica node (also outputs the set of nodes involved in service). But with the constraints of time, the model will make the actual time (t) tend to t_m (maximum time), regardless of the sensitivity of the transmission time for applicants, this is very useful when the network is busy, but when the network is idle, we should try to make the actual time tends to t_u (minimum time).

C. Comprehensive optimization model (C)

Model A seeks to minimize transmission time, without considering the service cost and the applicant's transmission time constraints. Model B takes minimum service cost as optimization objective, it will lead to that the transmission time is always tends to longer time within t_m constraint. Therefore, a balance strategy should be established between transfer time and service cost. The applicant has a certain degree of sensitivity on transmission time, and there is also a certain relationship between the service cost and the state of the grid system. If the key level of the task running in requester side is high, then it indicates that the transmission time has higher priority, in contrary, if the grid system is busy, then it should have higher priority.

We can take transmission time and service cost as optimization objective at the same time, and set a weighting factor to balance them. Complete optimization models is as shown below. L represents the difference between the actual transmission (t) and the minimum transfer time (t_u); U represents the whole cost of a service; ω is a weighting factor which can be used to balance transfer time and service costs; other specific constraints can be found in equations (1) - (5).

$$\min Z = \omega L + U \qquad (a)$$

$$s.t. \begin{cases} i = 1,2,...,k & (b) \\ S = \sum_{i=1}^{k} B_i & (c) \\ t_u = \begin{cases} M/Q & S \geq Q \\ M/S & S < Q \end{cases} & (d) \\ t = M\big/\sum_{i=1}^{k} y_i < t_m & (e) \\ L = t - t_u & (f) \\ zB_i \leq y_i \leq B_i & (g) \\ A_i = \begin{cases} A_i & y_i > 0 \\ 0 & y_i = 0 \end{cases} & (h) \\ U = \sum_{i=0}^{k} y_i(C_i + W_i) + A_i & (i) \end{cases} \tag{8}$$

The meaning of the linear programming model is: in the premise of satisfying the constraints, take the minimum value of Z, solve the values of decision variables y_i, and then we can further calculate the actual transmission bandwidth, transmission time t, and whole service costs.

IV. Simulation Experiment

There are many tools that can be used to solve ‘0-1’ integer programming problem, such as *Matlab*, *Lingo* and *Lindo*. As *Lingo10* is capable of flexible input/output and programming, and is more flexible than Matlab in solving complex integer programming problem, so we use Lingo10 to solve the models. In experiment some data are generated randomly, we observe the impact of various parameters on decision.

Here we give a network including 8 nodes, where N_1~N_7 are deployed replicas, N_0 is a requester. The corresponding parameters are given in table 2.

TABLE II VALUES OF B_i, C_i, W_i, A_i

Nodes / Paras	N_1	N2	N3	N_4	N_5	N_6	N_7
B_i	105	95	84	52	71	49	82
C_i+W_i	6	7	5	6	4	8	5
A_i	26	18	35	20	39	42	47

A. Purpose

Model A seeks to the minimum transmission time, and this will lead to higher cost to grid system. While in model B, the range of transmission time is given, so it must have impact on service cost. So we should check the effectiveness of model A and B, and compare the transmission time. In model C, a weighting factor is introduced to balance transmission time and service cost, so we should check its effectiveness also.

B. Experiment 1: test for minimum transmission time model

This experiment is designed to check the relationship between the aggregated bandwidth provied by the set of nodes output by model A and the maximum bandwidth of requester, and also to check effectiveness of model A. The values of B_i are given in table 3. By changing the values of Q, we conducted several experiments, and the experimental data is shown in Table 3.

TABLEIII. Decision-making results

Times	1	2	3	4	5
Q	50	70	90	110	130
Z	68	79	92	115	136
N_i	N_1, N_2	N_2, N_4	N_5	N_1, N_2, N_4	N_3, N_4

From figure 2 we can see that the decision-making results meet the constraints of the model, i.e., Z≤Q, and the difference between them is little. Therefore, the actual transmission bandwidth of requester from the participated nodes can reach to Q, and the minimum transmission time can be calculated by formula (4).

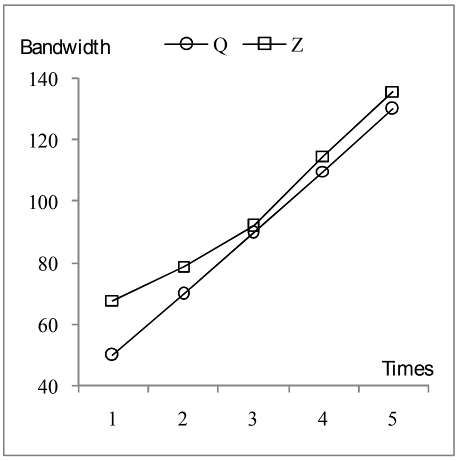

Figure 2. Comparison of Q and Z in model A

C. Experiment 2: Test for minimum cost model

(1) Performance analysis when M changes

This experiment is designed to check the relationship between *t* and t_m under specific condition when M is changed, and to check the relationship between V_a and Q. Let t_m=50, *q*=130, *z*=0.2, then observe a set of results for every value of M. The experimental data is shown in Table 4.

TABLEⅣ. Optimization results of model B when M changes

Times	1	2	3	4	5
M	2000	2500	3000	3500	4000
t_m	50	50	50	50	50
t	37.5	46.8	50	50	50
t_u	15.4	19.2	23.1	26.9	30.8
V_a	53.4	53.4	60	70	80
Q	130	130	130	130	130

It can be seen from Figure 3 that when *M* takes different values, the actual data transmission time *t* lies between t_m and t_u., and it is more closely with t_m, even overlap. The result is consistent with the constraints of formula (5). From figure 4 we can know that, the actual bandwidth achieved by requester is far less than its maximum bandwidth Q. So it leads to that the actual transmission time *t* is much larger than the minimum transfer time t_u.

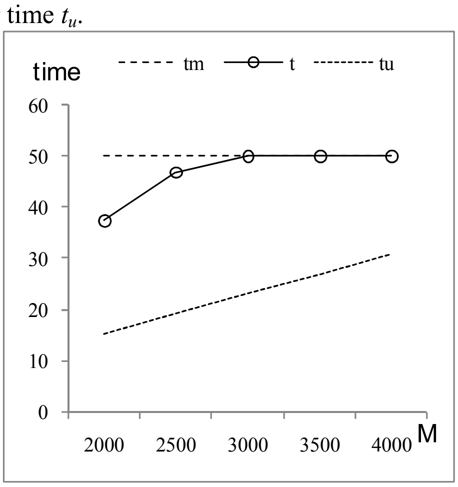

Figure 3. Impact of M on t in model B

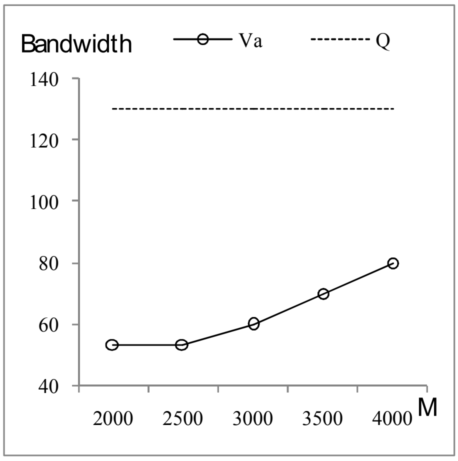

Figure 4. Impact of M on V_a in model B

Analysis: Since the minimum cost model at a given time constraints in order to achieve the minimum cost objective, will reduce the actual transmission bandwidth of the applicant. The state of grid is not considered in the optimization process. This can improve the quality of service and acceptance rate in peak time, but when the grid is idle, it will result in a large number of idle resources.

(2) Impact of t_m on the performance of model

This experiment is designed to check the impact of t_m on service cost. Maximum expected time constraint given by the applicant is an important basis for decision making, so for a service request we should check how t_m impacts on service cost. Let M=3500, q=120, z=0.2, then incrementally change the values of t_m, and every time record the result of service cost output by the model. Observe 5 sets of data, see table 5.

TABLE Ⅴ. Optimization results when t_m changes.

Times	1	2	3	4	5
t_m	30	35	40	45	50
cost	9931.25	7383.83	6620.65	5933.66	5816.90
t	30	32.5	35.8	43	49.3

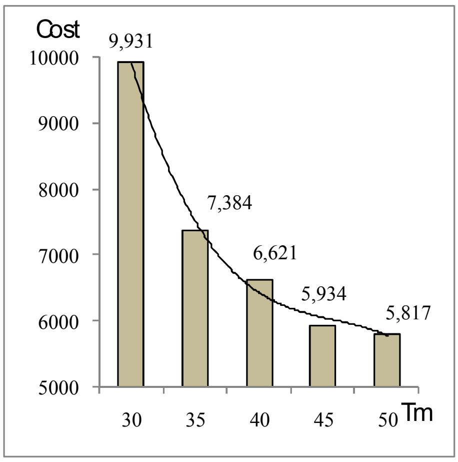

Figure 5. Impact of t_m on cost in model B

From figure 5 it can be seen that, as t_m increases, the whole service cost decreases, the difference is 4114 when t_m=30 and 50, and the cost is decreased by 41 percent. But by figure6, as t_m increases, t is always closely with t_m, the two curves is cross in the first time, and in the third the difference is a little more, but in the four and five times they gradually become close. This shows that under the constraint of t_m, the actual transmission time is still biased in favor of t_m.

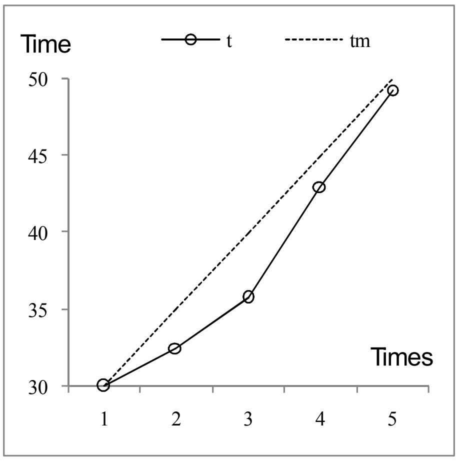

Figure 6. Impact of t_m on t in model B

D. Experiment 3: Test for comprehensive optimization model

Model A takes minimum transmission time as the optimization objective, and the service costs are not taken into account. In model B, the whole service cost is optimized under the constraint of expect maximum transmission time, so this leads to the actual transmission time tends to t_m. Therefore, in model C, a weighting factor is introduced to balance the time and cost. This experiment is designed to the check the trend of service cost and time when the weighting factor changes. Let M=3000, t_m=50, q=150, z=0.2, then change the value of ω and observe four sets of data, as shown in Table 4.

TABLEⅥ. the corresponding optimization results outputted by model C when ω changes

ω	40	60	80	100
t	45.2	28.3	24.0	20.0
t_u	20.0	20.0	20.0	20.0
t_m	50	50	50	50

It can be seen from figure 7, with the increases of weighting factor, the actual transmission time t which is close to the maximum transmission time (t_m) at the beginning, gradually moves to the minimum transmission time t_u. When ω=100, curves t and t_u intersects and achieves the minimum value. In this process, the curve gradually increases and the corresponding values increases to 27860 from the beginning value 19450, and the cost increases by 43.2%. From figure 8 we can see that as the increases of weighting factor, the service cost increases greatly, it just shows an opposite trend compared with curve t.

We can see that the weighting factor can balance transmission time and service cost effectively. If the applicant is sensitive to transmission time (or more critical services), we can increase the weight, so under the constraint of time we can make the actual transmission time t tends to the minimum transfer time t_u. In contrast, if the critical level of service is general and the status of grid is busy, then we can reduce the weighting factor, thus prolong the transmission time and reduce service costs.

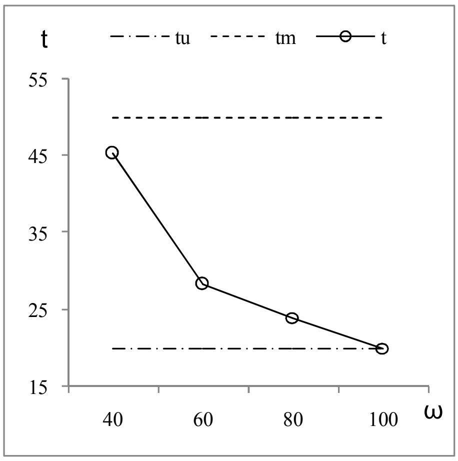

Figure 7. Impact of ω on t in model C

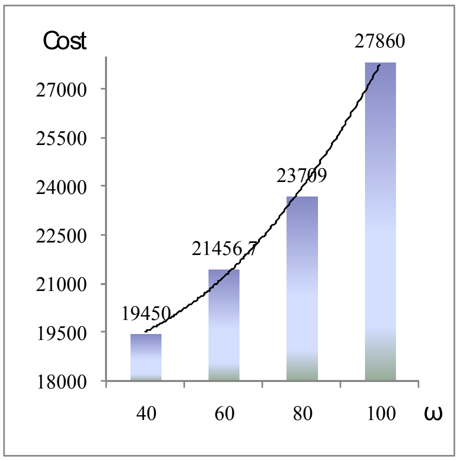

Figure 8. Impact of ω on cost in model C

E. Experimental Summary

For traditional parallel transfers that take minimized transmission time as optimization objective, a node selection model A is proposed. The model will cause a larger service cost, so the availability is better when the grid is free. In model B the range of transmission time is introduced, the model takes the minimized service cost as optimization objective, so compared with model A it has a greater advantage for the optimization of grid load. But the model always tend to longer time within time constraint regardless of grid status (idle or not), so it has a better usability when the status of grid is busy. In model C by introducing a weighting factor, the model not only focuses on service cost and transmission time, but also can make dynamically decision according to the critical level of transmission time and current status of grid. The weighting factor in model C palys a good role of balancing transmission time and service cost. Model C has better applicability and feasibility.

V. CONCLUSIONS

Guaranteeing the QoS of data service in grid is a challenge. Previous parallel transmission algorithms (based on multi-copy) less concerned about node selection and service cost optimization problem. The resource selection model (comprehensive optimization model C) proposed, under the condition of meeting the transmission time constraints, according to a variety of factors, can output the set of nodes involved in service. We achieved the optimization objective of balancing transmission time and service cost. Optimization of service cost and rational use of node resources can improve the acceptance rate and QoS of grid system in peak time. The comprehensive optimization model provides a useful reference for the guarantee of QoS for data grid and node selection.

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Ming-Cheng Qu is a Ph.D. in school of Computer Science and Technology of Harbin institute of technology (HIT). He received his BS and MS degree from HIT. His research interests include grid computing etc

Xiang-Hu Wu is a professor in school of Computer Science and Technology of Harbin Institute of Technology (HIT). He is a advanced member of CCF. His research interests include grid computing and embedded computing.